UNCLASSIFIED

AD 408 660

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

UNCLASSIFIED

63-4-2

BRL

MEMORANDUM REPORT NO. 1468
APRIL 1963

CALIBRATION OF PC-1000 CAMERAS BY MEANS OF STAR PHOTOGRAPHY

Myron W. Lawrence

RDT & E Project No. 1M222901A215

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1468

APRIL 1963

CALIBRATION OF PC-1000 CAMERAS BY MEANS OF STAR PHOTOGRAPHY

Myron W. Lawrence

Ballistic Measurements Laboratory

RDT & E Project No. 1M222901A215

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1468

MWLawrence/mec
Aberdeen Proving Ground, Md.
April 1963

CALIBRATION OF PC-1000 CAMERAS BY MEANS OF STAR PHOTOGRAPHY

ABSTRACT

Calibration of three PC-1000 cameras was performed utilizing approximate zenith exposures of stars. The calibration consists of determining the focal length, principal point, and lens distortion of each camera and corresponding estimates of precision derived from a rigorous least squares solution. Field work and data reduction procedures are described. Graphical presentation of lens distortion and a discussion of the results are included.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 The determination of position by means of artificial satellites is one basic objective of geodetic satellite projects. The accuracy requirement for such a project necessitates determining satellite positions to within a few meters. In order to obtain these positions by ground based cameras, directions to the satellite must be measured accurately to a few seconds of arc.

The purpose of the calibration described in this report was to determine the metric qualities of three specific cameras contemplated for use with project ANNA (DOD Geodetic Satellite Project). The calibration included determining the focal length, the principal point, and lens distortion of each camera utilizing zenith exposure of stars. Furthermore, the residuals of the corresponding least squares solutions were used for determining the amount of tangential lens distortion which, if present, will affect the precision of direction measurements.

1.2 In November 1961, three PC-1000 cameras (Fig. 1) Nos. 103, 104, and 109 were made available on a temporary loan basis from the Orlando Air Force Base, Florida. Electronic timing devices and other auxiliary equipment for coding star trails accompanied the cameras. Air Force personnel, familiar with the system, participated in the field work to insure acquisition of the necessary plates and related timing records.

Field work consisted of collecting a series of zenith star exposures using the PC-1000 cameras. Coding of star trail images was accomplished by the use of two types of shutters. Plates were measured on the STK-1 No. 818 Wild Stereocomparator and reduced by appropriate computer programs. Graphical presentations of the lens distortions and a brief discussion of the results are included.

2. FIELD INSTRUMENTATION AND PROCEDURES

2.1 PC-1000 Camera and Components

The PC-1000 camera features a 1000 millimeter f/5 lens. The plate size is 190 x 215 x 6 millimeters, with a usable field of about 170 x 170 millimeters. Plates used were flat to approximately 6 fringes and were coated with Eastman

FIG. 1
PC-1000 CAMERA

Kodak Spectroscopic type 103-F emulsion. The lens elements were aligned and assembled with a between-the-lens type shutter (internal shutter) in a camera housing by the Instrument Corporation of Florida. An in-front-of-the-lens shutter (capping shutter), manufactured by the Fred C. Henson Company of Pasadena, California and furnished by BRL was also used for the calibration. While using the capping shutter (Fig. 2) the internal shutter was kept open and vice-versa. All exposures were made using a maximum aperture and a clear filter.

2.2 Internal Shutter

When using the internal shutter, the exposure times were programmed by a slotted rotating disk. The shutter was activated by a light beam directed at the rotating slotted disk, which contained six slots of different lengths. When the disk rotated, the light beam passed through these slots energizing a photoelectric cell which was positioned opposite the light source. The resulting signal activated a circuit, which in turn opened the shutter. When the disk had rotated so that the light was again blocked off, the shutter closed. The length of the slot therefore controlled the length of the exposure and consequently the length of the star trail on the plate. The duration of the exposures given by the six slotted openings were approximately 4, 2, 1, 1/2, 1/4 and 1/8 seconds, with a lapse of about fifteen seconds between slots. The opening and closing times of the shutter were recorded on magnetic tape, together with corresponding one-per-second WWV time signals. The magnetic tape was then played back and recorded on Brush Recorder paper, where the exposure time could be visibly correlated with the WWV signal. Since radio reception was unreliable, the time signal was often submerged in the noise of the record. This made it difficult to define the times of the star trails when interpolating between WWV second pips. The entire program was repeated three times to insure that a sufficient number of star trails would be produced by this shutter. The time between runs was approximately two minutes. After the plate was developed the trails of different lengths were studied and it was decided that trails produced by the 1/4 second slot could be best utilized.

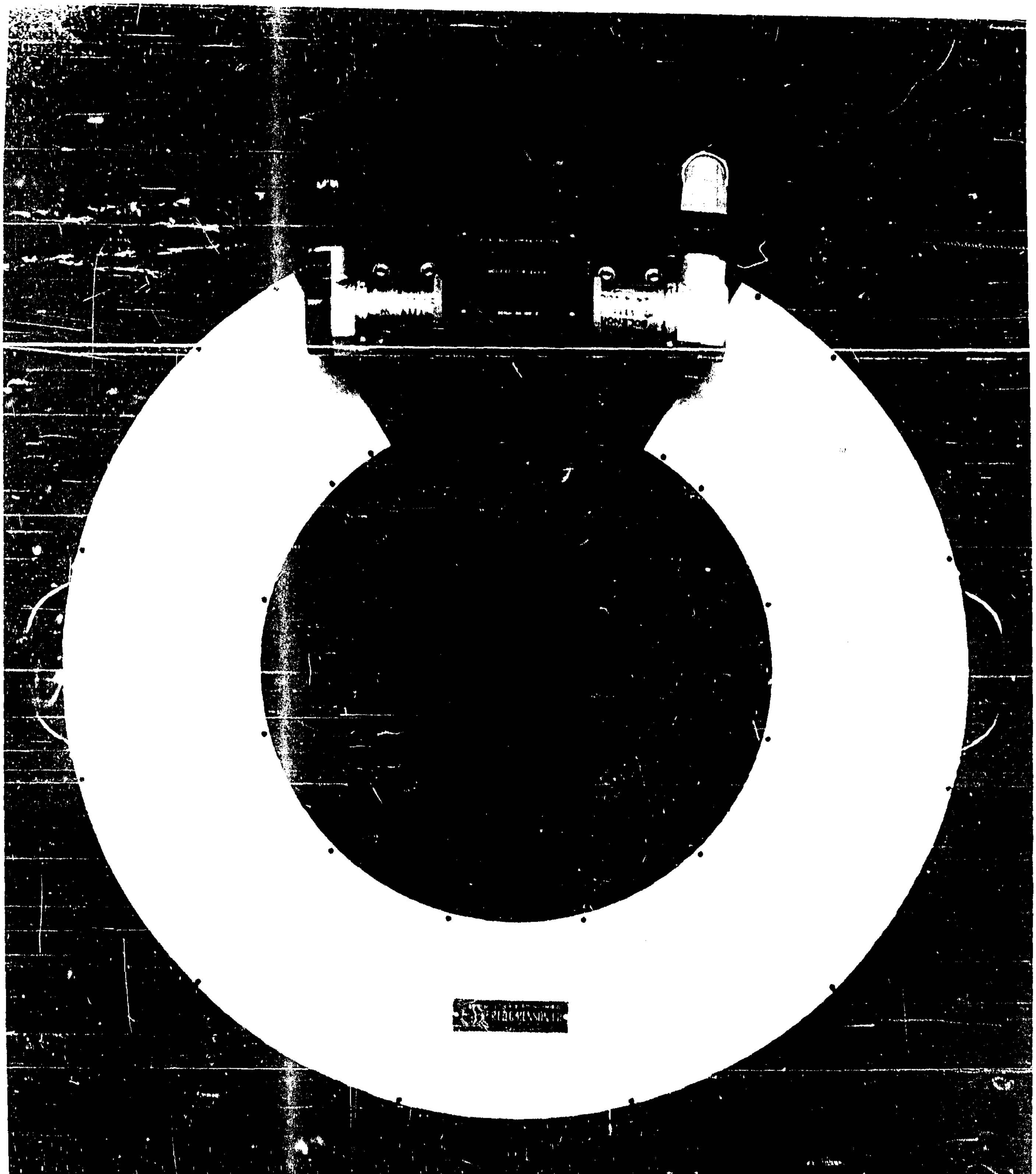


FIG. 2 - CAPPING SHUTTER

2.3 Capping Shutter

The capping shutter was activated by a one-per-second frequency standard pulse which had been previously synchronized with WWV. Therefore, the reception difficulty encountered while using the internal shutter was nonexistent. The opening and closing times of the shutter were adjusted so as to occur within one millisecond on the second. The shutter program and the pulse from the frequency standard were recorded simultaneously on Brush Recorder paper in order to facilitate analysis during data reduction. The shutter program used was: open five seconds -- closed one second -- repeated six times. This pattern permitted five images to be measured by setting the measuring mark between the corresponding star images. Since a line is more easily detected on a plate than a short dash or dot, images produced while using the capping shutter were more suited for the purpose than images produced with the internal shutter. In addition, the time-coded star trails obtained by the capping shutter aided in locating many of the images produced by the internal shutter that otherwise might not have been identifiable. Table 1 is a summary of the numbers of stars which were measured and used in the calibration.

TABLE 1

NUMBER OF STARS MEASURED AND USED

	Camera 103		Camera 104		Camera 109	
	Measured	Used	Measured	Used	Measured	Used
Capping Shutter	55	48	113	102	88	75
Internal Shutter	20	17	35	32	25	19

NOTE: Some of the stars that were measured were not used in the calibration because of marginal image quality.

2.4 Temperature, Pressure, Humidity

Temperature, pressure, and humidity readings were taken during the time the plate was being exposed. These values were then used in the computation of refraction corrections for the star positions.

2.5 Camera Orientation

The three cameras were oriented approximately at zero degree zenith distance.

3. REDUCTIONS

3.1 Plate Measurements

For each plate, a duplicate negative was made which served as the work plate on which unidentified and identified stars were marked and numbered for the measuring program. This procedure minimized the possibility of damaging the original plate. The identified stars were used to determine a preliminary camera orientation which then was used to identify all the stars selected for the calibration. During the measuring process, the duplicate plate was placed on the right (px and py) side of the stereocomparator and the original plate on the left (x and y) side. By properly utilizing the swing and px-py motions of the stereocomparator, the operator viewed the marked stars with the right ocular and proceeded to measure the stars on the original plate as viewed with the left ocular. Fiducial marks were measured in addition to the stars in order to define a convenient reference system for determining the coordinates of the principal point. These measurements also allow scale corrections for emulsion shrinkage to be made, based on the calibrated distances between fiducial marks.

3.2 Sequence of Data Reductions

For each camera calibration, the following sequence of steps was followed:

3.2.1 Comparator Reduction Program

3.2.2 Preliminary Star Identification and Star Reduction Program

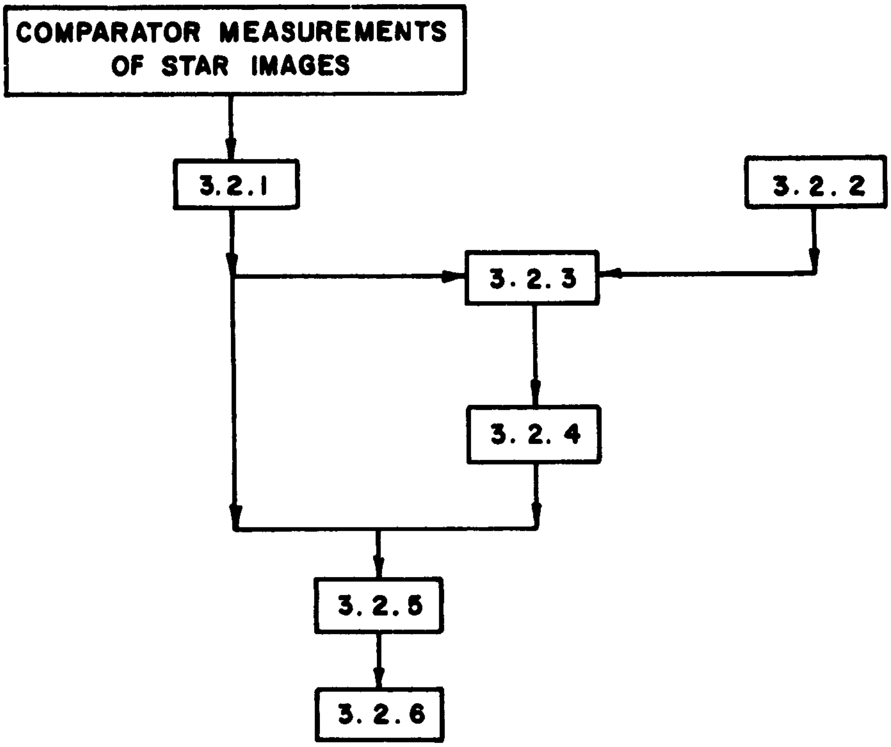
3.2.3 Preliminary Camera Orientation Program

3.2.4 Star Identification and Reduction Program

3.2.5 Camera Orientation Program

3.2.6 Plotting Program

The following flow diagram indicates the sequence of reductions.



3.2.1 <u>Comparator Reduction Program [1]*</u>

The essential steps in the comparator program are:

(a) correct any systematic comparator errors

* See references at end of report.

(b) form arithmetic averages for multiple settings of star measurements and if desired -

compute weight factors from the random discrepancies present in each set of measurements,

or compute weight factors as a function of the angle of incidence,

or introduce weights determined a priori.

(c) reduce all plate measurements to an origin as defined by the intersection of two lines joining the two pairs of opposite fiducial marks

(d) rotate the comparator coordinate system until it is parallel to a specific set of fiducial marks

(e) shift the origin to the principal point if x_p and y_p are known

(f) apply lens distortion corrections

NOTE: Only steps (a) through (d) are required for a camera calibration.

3.2.2 Preliminary Star Identification and Star Reduction Program

Right ascension and declination of the center of the plate are derived from the azimuth, zenith distance and instant of exposure by means of formulas from Chauvenet's Spherical Trigonometry. Utilizing these computed values, together with appropriate star charts, several of the brightest stars on the exposed plate can be readily identified. Right ascensions and declinations for these stars are obtained from a star catalogue and used in the Star Reduction Program [2] to obtain standard coordinates.

3.2.3 Preliminary Camera Orientation Program [3]

The purpose of this program is to obtain good approximate values for the camera orientation elements α, ω, κ, c, x_p and y_p. (The orientation elements are defined in Section 3.2.5). Input for this program consists of standard coordinates and plate coordinates of the preliminary stars together with approximate values of α, ω, and κ, as computed from Formula 8 of [4].

3.2.4 Star Identification and Reduction Program [2]

The Star Identification Program uses orientation elements obtained from the Preliminary Camera Orientation Program and plate coordinates from the Comparator Reduction Program to obtain approximate right ascensions and declinations of the unidentified stars. Each star is identified in the program by comparing this approximate right ascension and declination with corresponding values in a star catalogue, (the AGK_3 Catalogue was used for the three PC-1000 camera calibrations).

The standard coordinates for each star are then computed using the catalogue values.

3.2.5 Camera Orientation Program [3]

The Input* for this program consists of the standard coordinates from the Star Reduction Program (3.2.4), and corresponding plate coordinates as obtained from the Comparator Reduction Program (3.2.1).

The Output* consists of the orientation elements α, ω, κ and the required calibration parameters c, x_p, y_p, K_0, K_1, K_2, K_3 where:

α, ω, κ are three rotation parameters

c * is the adjusted focal length

x_p and y_p are the coordinates of the principal point, and

K_0, K_1, K_2 and K_3 are distortion coefficients used to compute radial distortion as:

$\Delta = K_0 r + K_1 r^3 + K_2 r^5 + K_3 r^7$; ($\Delta$ is the amount of radial distortion and r is the radial distance from the principal point)

* linear parameters are given in meters.

3.2.6 Plotting Program

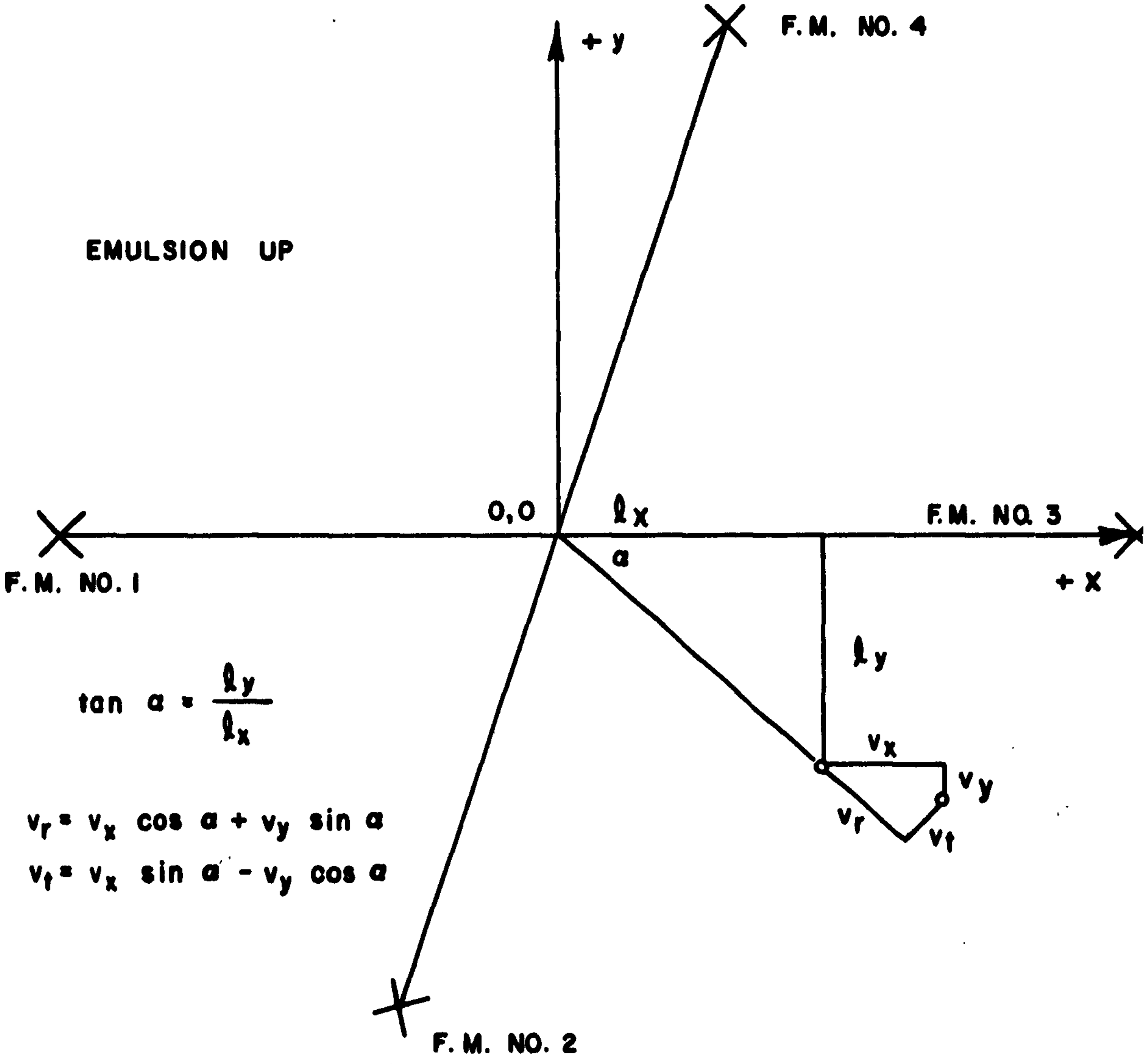
The purpose of this program is to compute radial and tangential distortion residuals (v_r and v_t) and to present these values in a graphical form (see Fig. 3).

Input values for the program consist of the plate coordinates (ℓ_x and ℓ_y) of each star as obtained from the Comparator Reduction Program, the residual errors of these plate coordinate (v_x and v_y) and the coordinates of the principal point (x_p and y_p) as obtained by a least squares solution from the Camera Orientation Program. The v_x and v_y values are converted into v_r and v_t values and scaled up by a predetermined scale factor to insure a suitable graphical presentation. The origin of the plot is translated to the principal point by introducing the corresponding x_p and y_p values.

Results of the Plotting Program are shown in Figs. 4A through 4C, which present radial and tangential distortion values as obtained for the three PC-1000 cameras. These values include measuring errors corresponding to a standard deviation of approximately 8 microns.

4. DIRECTION PROGRAM

An investigation was made concerning the influence of the two types of shutters used upon the metric quality of the corresponding photographic record. This required the computing of two camera orientations, using only the stars imaged by each shutter. Based on these results, and applying formulas and procedures similar to those used in 3.6 of [5], directions were computed for two fictitious points corresponding to the center and a corner of the plate. Results as tabulated in Table 2 show that the differences in directions produced by the two shutters were small.



Where

l_x l_y ARE PLATE COORDINATES OF STAR
v_x v_y ARE RESIDUALS IN THE PLATE COORDINATES
v_r v_t ARE THE CORRESPONDING RADIAL AND TANGENTIAL DISTORTION COMPONENTS

FIG. 3 – PLOTTING PROGRAM

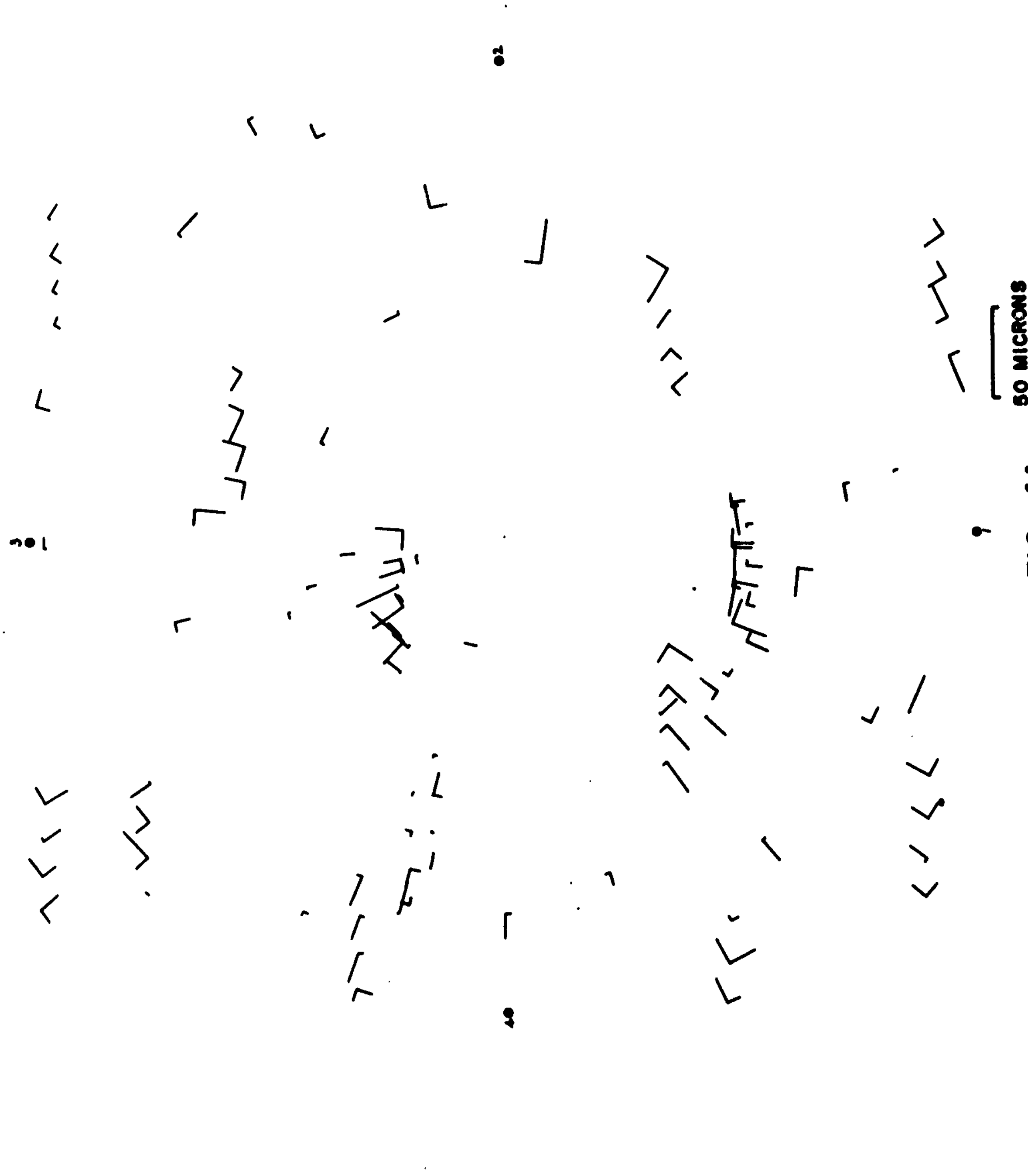
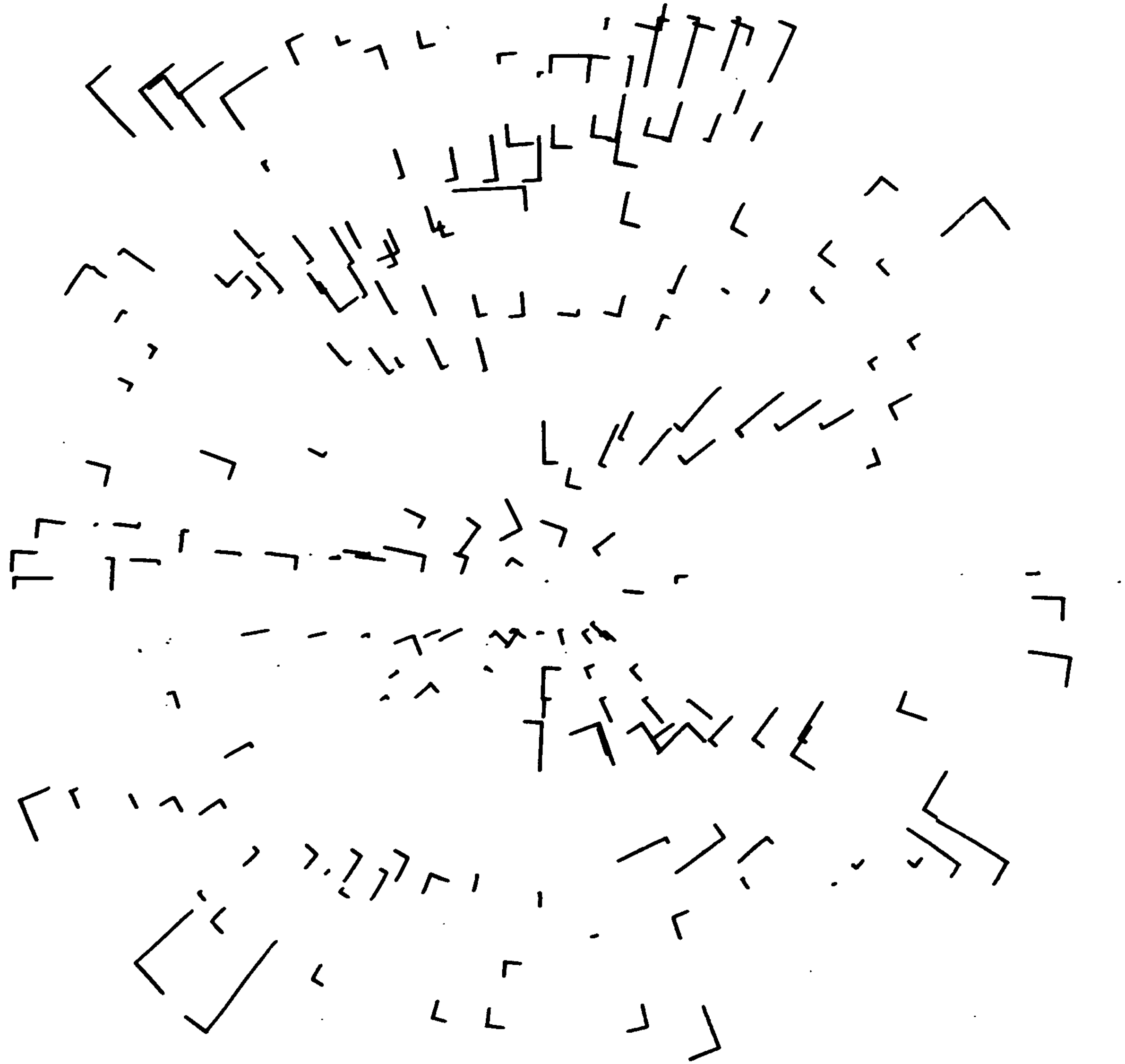
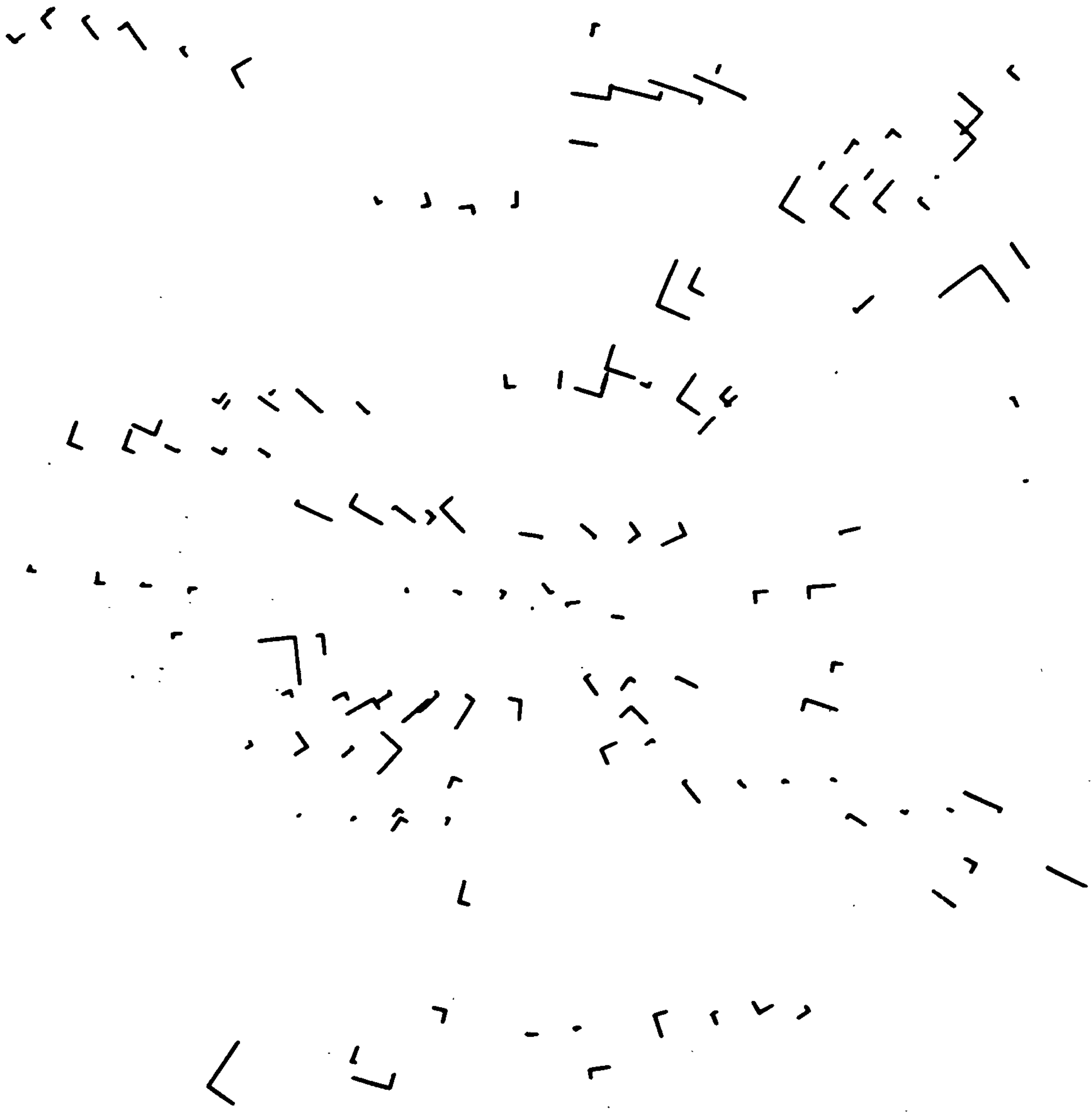


FIG. 4A
RADIAL AND TANGENTIAL DISTORTION
PC-1000 NO. 103



50 MICRONS

FIG. 4B
RADIAL AND TANGENTIAL DISTORTION



50 MICRONS

FIG. 4C

RADIAL AND TANGENTIAL DISTORTION

PC-1000 NO. 109

TABLE 2

RESULTS OF DIRECTION PROGRAM

	Center of Plate $\ell_x = \ell_y = 0$	Corner of Plate $\ell_x = \ell_y = .065$ meters
	CAMERA 103	
$\Delta''\delta$	+1.00	+1.01
$(\Delta''\alpha)(\cos\delta)$	-0.35	-1.04
	CAMERA 104	
$\Delta''\delta$	+0.37	+0.67
$(\Delta''\alpha)(\cos\delta)$	-0.70	-1.05
	CAMERA 109	
$\Delta''\delta$	+0.16	-0.14
$(\Delta''\alpha)(\cos\delta)$	-1.16	+0.70

$\Delta''\delta$ is the difference in declination and

$\Delta''\alpha$ is the difference in right ascension as obtained by the two types of shutters.

5. CALIBRATION RESULTS

The results of the calibrations are shown in Table 3 and Figs. 5 through 11. The one sigma error level of the distortion curves shown in Figs. 7, 9, and 11 resulted from the fact that a crossover point of .065 meters was enforced.

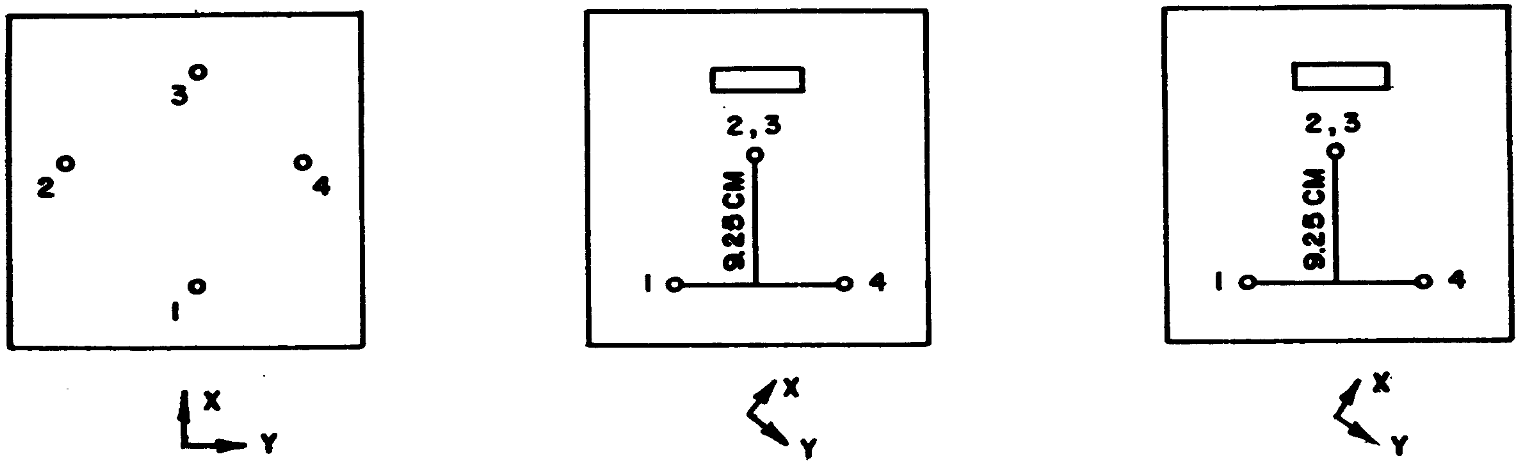
TABLE 3

	Camera 103[1]		Camera 104[2]		Camera 109[2]	
c^*	+.10143219	+01	+.10213468	+01	+.10164131	+01
x_p	+.11227386	-02	+.37157433	-02	+.38252082	-02
y_p	-.48750155	-03	-.31050232	-02	-.42985370	-02
c	+.10145372	+01	+.10216897	+01	+.10165417	+01
K_0	-.21230287	-03	-.33579670	-03	-.12652302	-03
K_1	+.81546644	-01	+.73673675	-01	+.68225669	-02
K_2	-.95307218	+01	+.17542068	+01	+.74248385	+01
K_3	+.50249533	+03	-.90007479	+02	-.46195770	+03

Linear parameters are given in meters, c is the calibrated focal length corresponding to a cross-over point of the distortion curve of .065 meters.

[1] In the case of camera 103, the principal point was referred to the intersection of the two lines joining opposite pairs of fiducial marks.

[2] In the case of cameras 104 and 109, the dark slide was not completely pulled when the plates were exposed; as a result fiducial marks 2 and 3 were not imaged. Therefore, the principal point was referred to a point on the perpendicular bisector and at a distance of 9.25cm from line 1-4. Coordinates of the fiducial marks are also given for scale corrections (see Fig. 5).



CAMERA 103 CAMERA 104 CAMERA 109

NEGATIVE PLATES
EMULSION DOWN

PT.	X	Y	X	Y	X	Y
1	-.86808943 -01	0	-.12081454 +00	0	-.12084688 +00	0
2	-.30048607 -03	-.87611741 -01	0	0	0	0
3	+.87089469 -.01	0	0	0	0	0
4	+.29950413 - 03	+.87324246-01	-.20833257 - 01	+.11900177+ 00	-.20763194 -01	+.11904790 +00
P. P.	+.11227386 - 02	-.48750155-03	+.37157433 - 02	-.31050232 -02	+.38252082 -02	-.42985370 -02

FIG. 5
COORDINATES OF FIDUCIAL MARKS & PRINCIPAL POINT (METERS)

FIG. 6

HISTOGRAM AND NORMAL DISTRIBUTION CURVE OF RESIDUAL ERRORS OF THE PLATE MEASUREMENTS
PC-1000 NO. 103

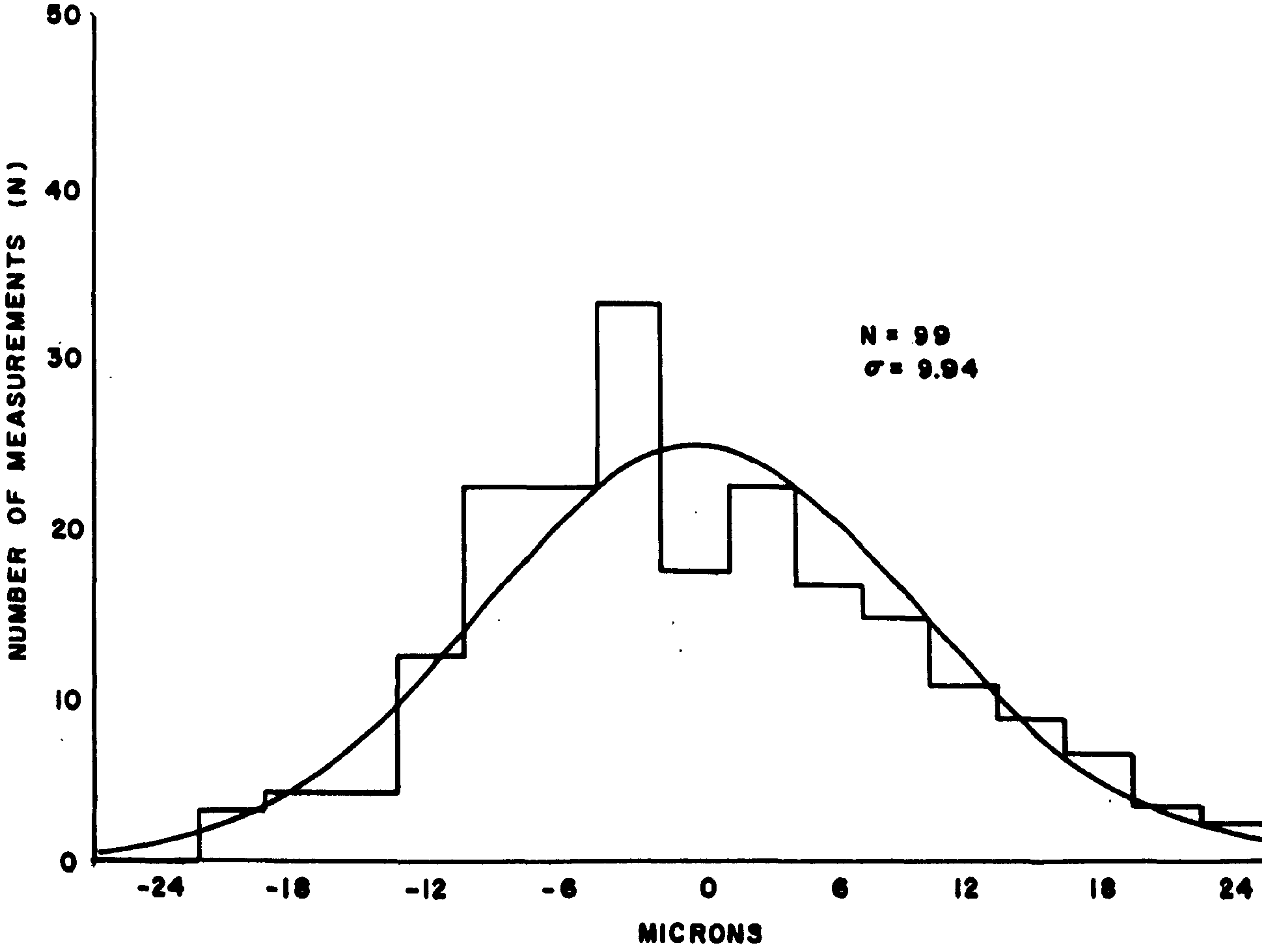


FIG. 7
DISTORTION CURVE
PC-1000 NO. 103

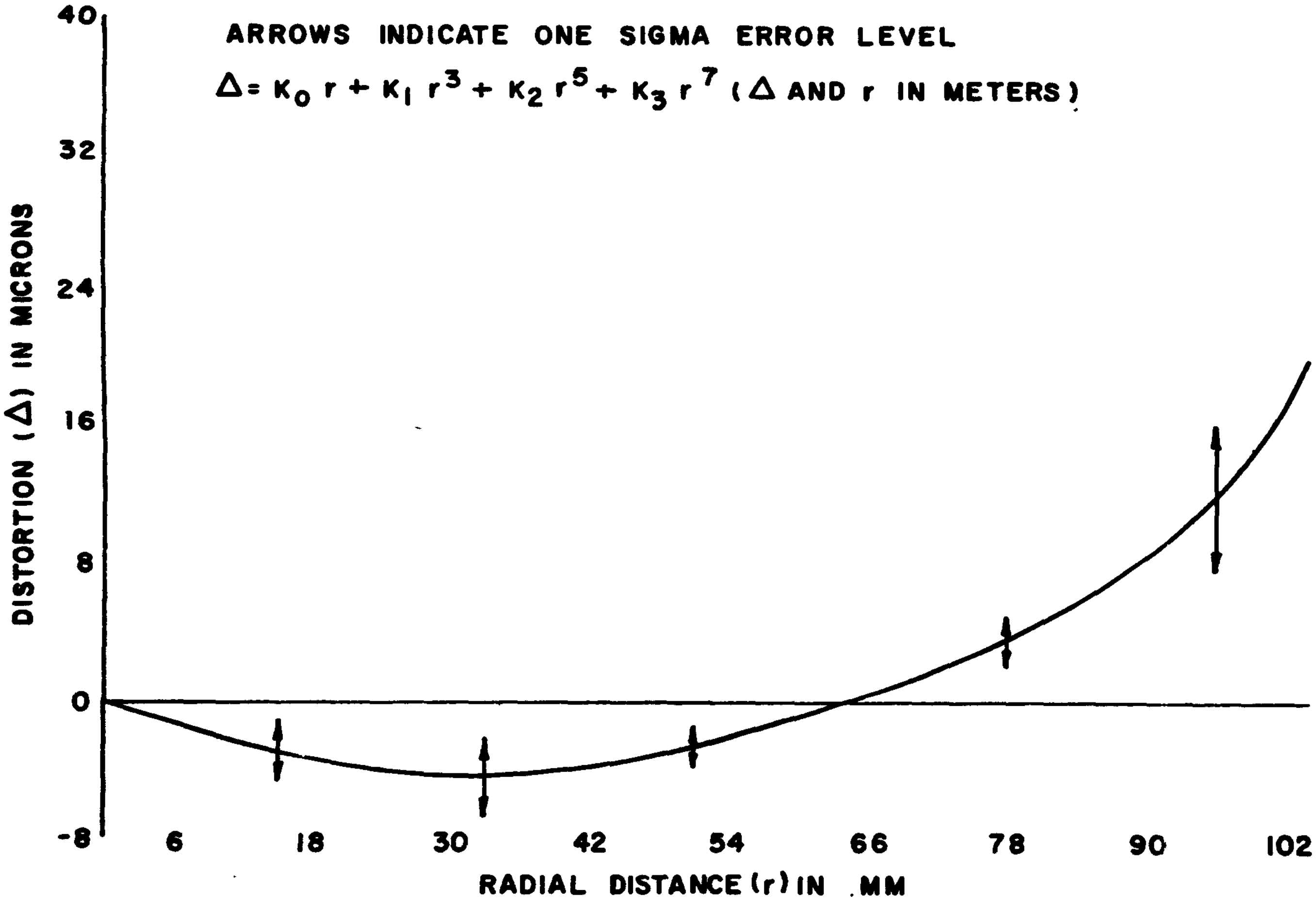
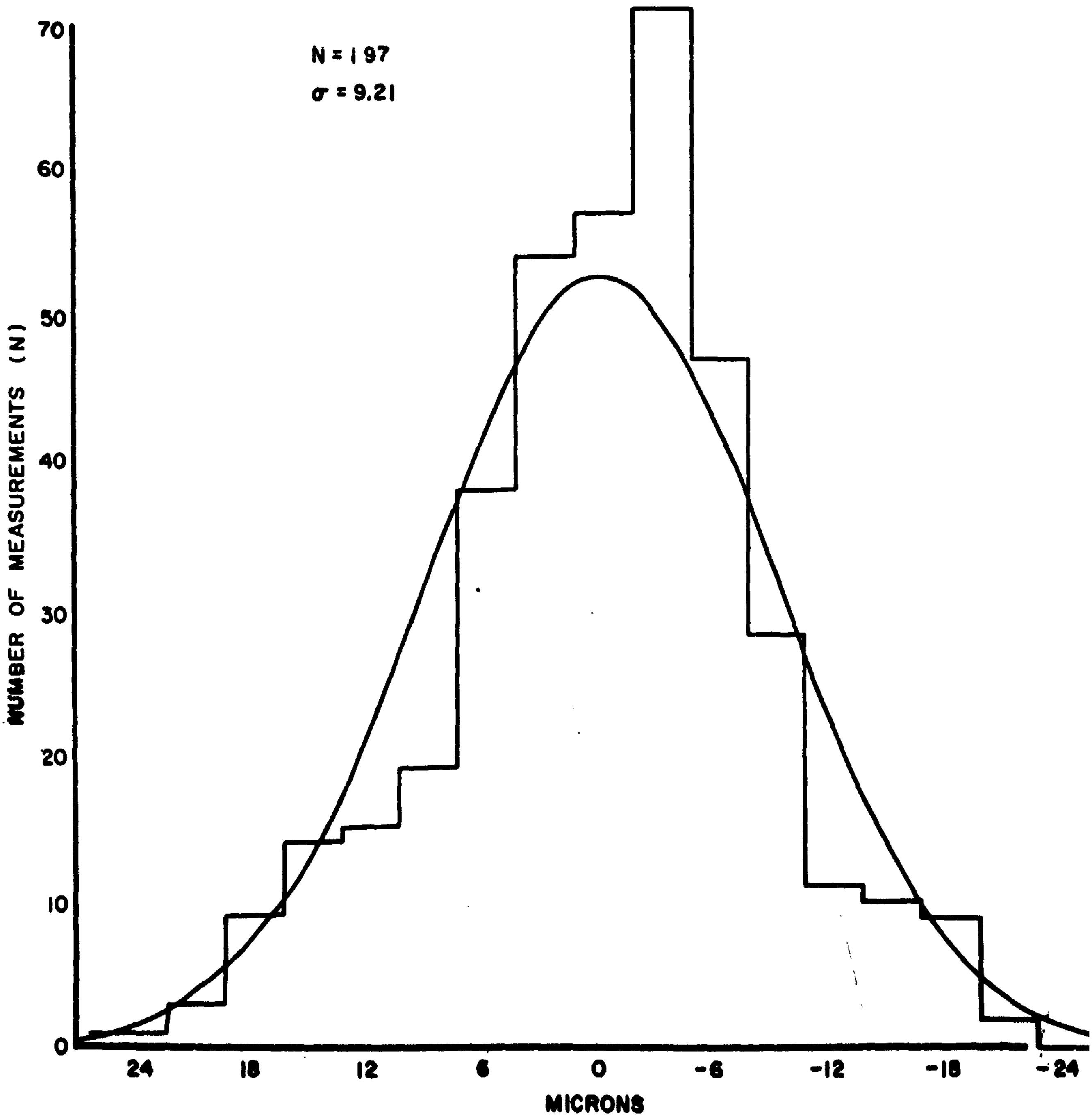


FIG. 8

HISTOGRAM AND NORMAL DISTRIBUTION CURVE OF RESIDUAL ERRORS OF THE PLATE MEASUREMENTS

PC-1000 NO. 104



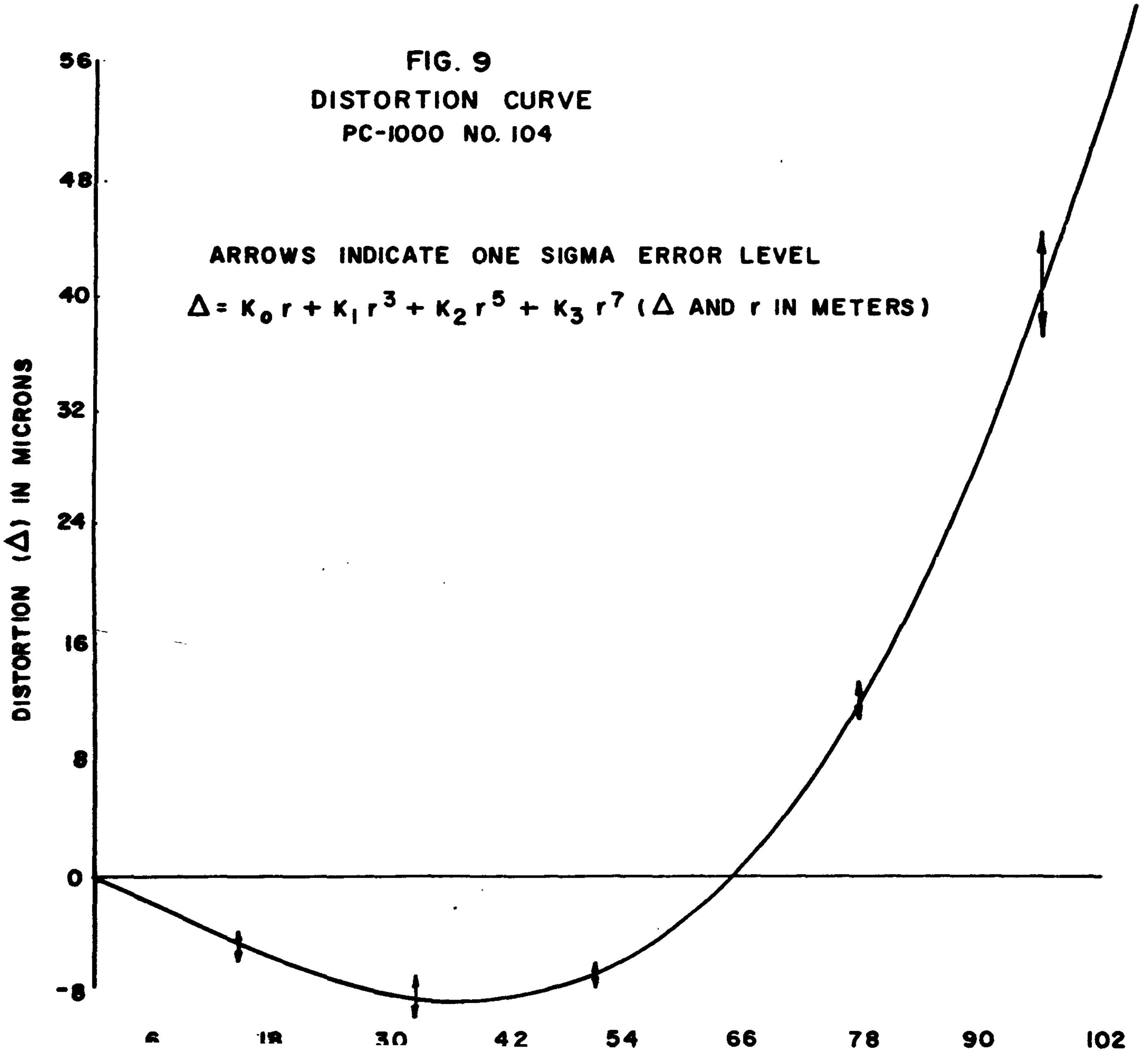


FIG. 9
DISTORTION CURVE
PC-1000 NO. 104

FIG. 10

HISTOGRAM AND NORMAL DISTRIBUTION CURVE OF RESIDUAL ERRORS OF THE PLATE MEASUREMENTS

PC-1000 NO. 109

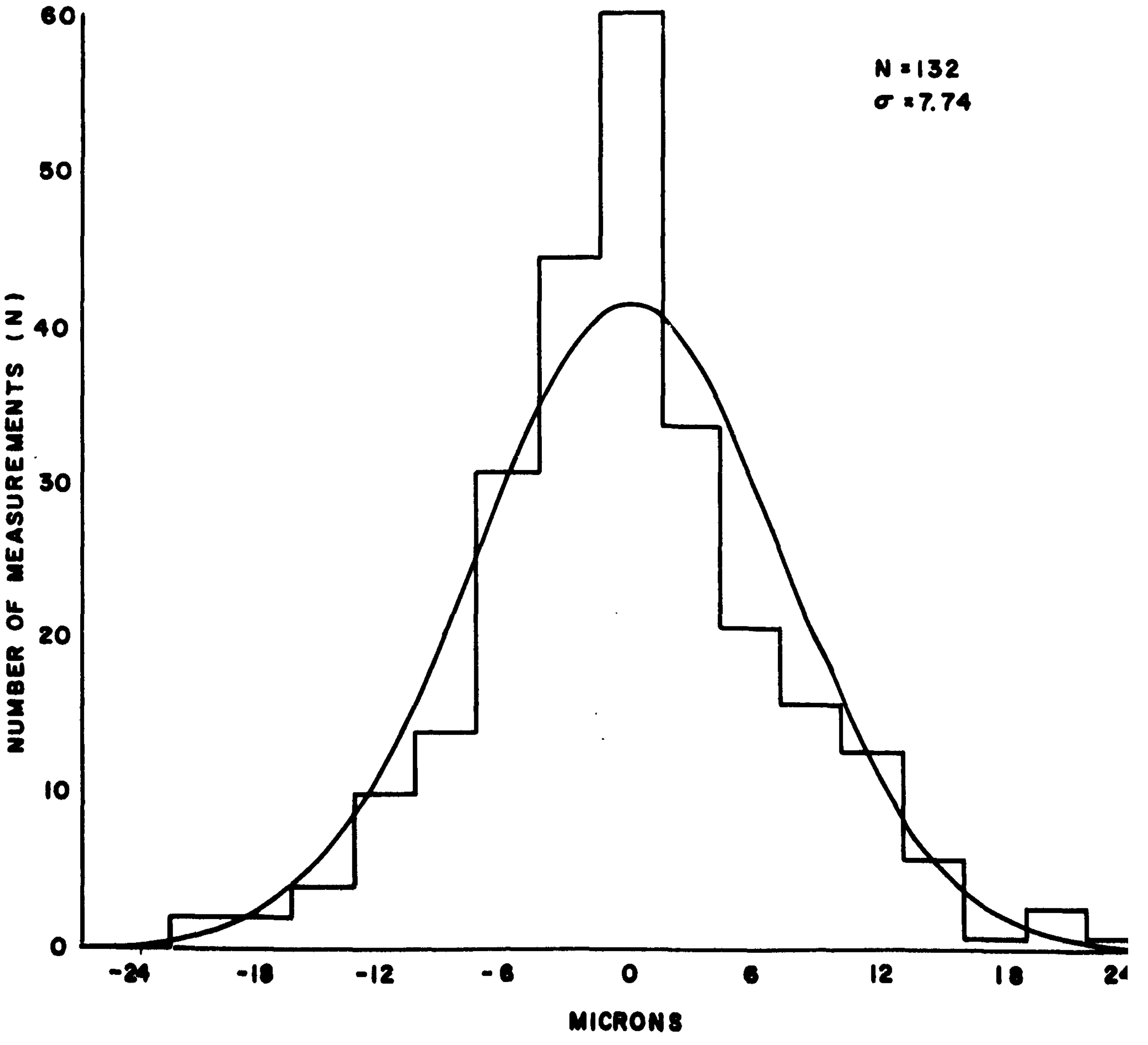
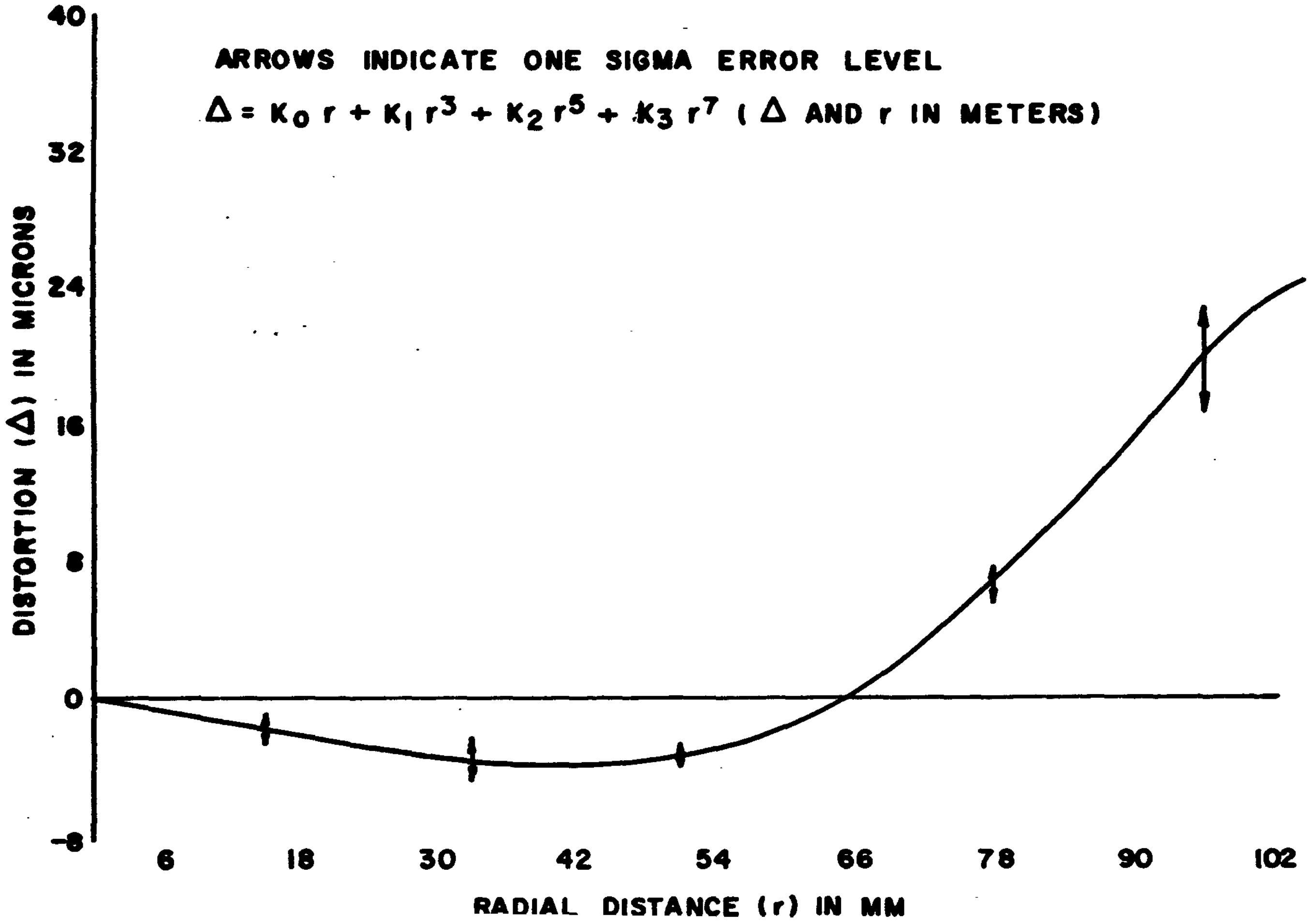


FIG. 11

DISTORTION CURVE
PC-1000 NO. 109



6. CONCLUSIONS

As expected from a lens with a small angle of view (10°), the radial distortion characteristics of the PC-1000 cameras are adequate to meet most precision measurement requirements. However, the presence of large amounts of tangential distortion as shown by Figs. 4A to 4C has the effect of limiting the camera as a precision measuring instrument.

The significance of the calibration results, given in Section 5, is especially impaired because of the relatively small number of star images produced by the PC-1000 camera. A large number of star images distributed evenly over the plate is required to interpret significantly the proven distortion asymmetries. To insure required star density for the PC-1000 cameras, a star must be imaged on a plate several times. Such an operation, however, would require a camera mount of exceptionally high stability.

Myron W. Lawrence
MYRON W. LAWRENCE

REFERENCES

1. Wooten, A. Roberta. Mono and Stereocomparator Reduction Program for the Ordvac. BRL Memo Report No. 1406, May 1962.

2. Wooten, A. Roberta. ORDVAC Programs for Star Identification and Computation of Standard Coordinates. BRL Memo Report No. 1451, January 1963.

3. Schmid, H. H. A General Analytical Solution to the Problem of Photogrammetry. BRL Report No. 1065, July 1959.

4. Schmid, H. H. An Analytical Treatment of the Orientation of a Photogrammetric Camera. BRL Report No. 880, October 1953.

5. Lawrence, Myron W. Photogrammetric Evaluation of Aircraft Gun Firings at High Altitudes. BRL Report No. 1106, August 1960.

DISTRIBUTION LIST

No. of Copies	Organization
10	Director Armed Services Technical Information Agency ATTN: TIPCR Arlington Hall Station Arlington 12, Virginia
1	Joint Coordinating Committee on Guided Missiles Office of the Assistant Secretary of Defense (R&D) The Pentagon Washington 25, D. C.
1	Director of Defense Research & Engineering (OSD) Director/Guided Missiles The Pentagon Washington 25, D. C.
1	Commanding General U. S. Army Materiel Command ATTN: AMCRD-RS-PE-Bal Research & Development Directorate Washington 25, D. C.
1	Commanding Officer Harry Diamond Laboratories ATTN: Technical Information Office, Branch 012 Washington 25, D. C.
3	Commanding General U. S. Army Missile Command ATTN: Dr. Ernst Stuhlinger Dr. Hellmut Holzer Dr. Bruns Redstone Arsenal, Alabama
6	Commanding General White Sands Missile Range ATTN: Mr. David Herzsmark Mr. Ben Billips Mr. John Phillips Mr. Jed Durrenberger New Mexico
1	Redstone Scientific Information Center ATTN: Chief, Document Section U. S. Army Missile Command Redstone Arsenal, Alabama
1	Commanding General U. S. Army Signal Corps Engineering Labs. ATTN: Tech Document Center Fort Monmouth, New Jersey
2	Commanding Officer Army Research Office (Durham) ATTN: CRD-AA-IPL Dr. Theodore W. Schmidt Box CM, Duke Station Durham, North Carolina
3	Chief, Bureau of Naval Weapons ATTN: DIS-33 Department of the Navy Washington 25, D. C.
2	Commander Naval Ordnance Laboratory White Oak Silver Spring 19, Maryland
1	Commander U. S. Naval Ordnance Test Station ATTN: Technical Library China Lake, California
2	Commander Naval Proving Ground ATTN: Dr. W. A. Kemper Dr. C. J. Cohen Dahlgren, Virginia
1	Commander U. S. Naval Photographic Interpretation Center Anacostia Station Washington 20, D. C.

DISTRIBUTION LIST

No. of Copies	Organization
1	Director U. S. Naval Research Laboratory Washington 25, D. C.
1	Commander U. S. Naval Air Development Center Johnsville, Pennsylvania
1	Commanding Officer Naval Air Test Center Patuxent River, Maryland
1	Chief of Naval Operations Department of the Navy Washington 25, D. C.
3	Commander U. S. Naval Hydrographic Center ATTN: Mr. John O. Davis Mr. Leo V. Stress Washington 25, D. C.
2	Commander U. S. Naval Air Missile Test Center Point Mugu, California
2	Director U. S. Naval Observatory ATTN: Dr. William Markowitz Dr. C. M. Clemence Washington 25, D. C.
1	AUL Maxwell Air Force Base Alabama
3	APGC (PGTRI, PGEES, Mr. W. A. Brown) Eglin Air Force Base Florida
2	AFMTC ATTN: (AFMT Tech Lib. MU-135) Patrick Air Force Base Florida
2	AFCRL (Geophysics Research Directorate) L. G. Hanscom Field Bedford, Massachusetts
1	ARL Wright-Patterson Air Force Base Ohio
1	RADC Griffiss Air Force Base Rome, New York
1	Commanding Officer Air Force Aeronautical Chart Service ATTN: Division of Photogrammetry Washington, D. C.
3	AFMDC ATTN: Dr. Paul D. Jose Mr. Charles A. Bagley Holloman Air Force Base New Mexico
1	APCS ATTN: Capt. Charles J. Finley Orlando Air Force Base Florida
1	ACIC ATTN: Chief Photogrammetry Research Branch Mr. Edwin Roth Air, Photographic & Charting Service (MATS) Second & Arsenal Streets St. Louis 18, Missouri

DISTRIBUTION LIST

No. of Copies	Organization
1	Director National Science Foundation ATTN: Technical Library Washington, D. C.
3	Director U. S. Geological Survey ATTN: Chief, Topographic Eng. Mr. Russel K. Bean Mr. R. E. Altenhofen Washington 25, D. C.
7	Commanding Officer U. S. Army Map Service ATTN: Photogrammetric Division Col. Robert C. Miller Mr. A. Nowicki Mr. J. Theis Mr. C. Born Mr. James P. Webb, Chief CSI Div. Mr. S. W. Henriksen, Dept. of Geodesy Corps of Engineers 6500 Brooks Lane Washington 16, D. C.
1	NASA Goddard Space Flight Development Center Satellite Application Division 4555 Overlook Avenue, S. W. Washington 25, D. C.
1	Director National Aeronautics & Space Agency ATTN: Mr. Richard M. Dickerson Langley Research Center Langley Field, Virginia
1	Director National Bureau of Standards ATTN: Dr. Irvine C. Gardner Washington 25, D. C.
9	Director U. S. Coast & Geodetic Survey ATTN: Capt. L. W. Swanson Mr. G. C. Tewinkel Mr. Charles Whitten Mr. L. G. Simmons Capt. F. R. Gossett Mr. Wm. D. Harris LCDR E. A. Taylor CDR Woodcock Mr. Erwin Schmid Washington 25, D. C.
1	U. S. Geological Survey ATTN: Mr. Morris M. Thompson 1109 N. Highland Street Arlington, Virginia
1	U. S. Department of the Interior ATTN: Henry P. Cate, Jr. Chief, Branch of Computat Bureau of Land Management 555 Cordova Street Anchorage, Alaska
5	Director Geodesy, Intelligence & Mapping R&D Agency ATTN: Mr. William C. Cude (Dir) Mr. D. Esten Mr. John T. Pennington Mr. Matos Dr. H. H. Schmid Fort Belvoir, Virginia
4	Goddard Space Flight Center NASA ATTN: Mr. W. M. Kaula, Theoretical Division Mr. William B. Taylor Dr. Nordberg Dr. John O'Keefe Greenbelt, Maryland

DISTRIBUTION LIST

No. of Copies	Organization
2	U. S. Atomic Energy Commission Sandia Corporation P. O. Box 5800 Albuquerque, New Mexico
1	Aeroflex Laboratories Incorporated ATTN: C. L. Benesh Eng. Sales Mgr. 48-25 36th Street Long Island City 1, New York
1	Applied Physics Laboratory ATTN: Dr. W. H. Guier The Johns Hopkins University Howard County, Maryland
2	Autometric Corporation Paramount Building ATTN: Dr. Ulrich Heidelauf Mr. E. L. Merritt New York 36, New York
1	Bausch & Lomb Optical Co. ATTN: Mr. Heinz Gruner 262 St. Paul Street Rochester, New York
1	Bausch & Lomb Incorporated ATTN: Mr. Rex R. McHail, Dept. G-53 62663 Lamb Park Rochester 2, New York
1	Brookhaven National Laboratory ATTN: O. B. Reading Upton, New York
1	Bendix Aviation Corporation ATTN: V. A. van Praag Computer Division 5630 Arbor Vitae Street Los Angeles 45, California
1	Cincinnati Observatory ATTN: Dr. Paul Herget Cincinnati, Ohio

No. of Copies	Organization
1	D. Brown Associates, Inc. Data Processing Specialists P. O. Box 1197 Eau Gallie, Florida
3	Instrument Corporation of Florida Box 1226 Melbourne, Florida
1	Institute of Geophysics and Planetary Physics ATTN: Dr. G. J. F. MacDonald Los Angeles Laboratories University of California Los Angeles 24, California
1	International Business Machine Corporation ATTN: Mr. John V. Sharp Endicott, New York
2	Lockwood Kessler & Bartlett, Inc. ATTN: Mr. Harold Johnson Mr. Ford Bartlett 1 Aerial Way Syosset, New York
1	Photogrammetry, Inc. ATTN: Mr. Gomer T.McNeil Silver Spring, Maryland
1	RCA Service Co., Incorporated ATTN: RCA Data Reduction Gr. Analysis Unit Patrick Air Force Base, Florida
1	Ramo-Wooldridge Corporation ATTN: Dr. E. Stern 5730 Arbor Vitae Street P. O. Box 45067 Airport Station Los Angeles 45, California
1	Palmer Physical Laboratory ATTN: Dr. R. H. Dicke Princeton University Princeton, New Jersey

DISTRIBUTION LIST

No. of Copies	Organization
3	Space Systems Laboratory ATTN: Mr. A. Schiefner 526 Fee Avenue Melbourne, Florida
1	Technical Operations, Inc. ATTN: Mr. Samuel S. Holland Burlington, Massachusetts
1	Telecomputing Corporation Engineering Services Division Burbank, California
1	Transmares Corporation 15 William Street New York 5, New York
1	Western Development Labs. Philco Corporation ATTN: Mr. Eric Besag 3875 Fabian Way Palo Alto, California
3	Wild Heerbrugg Instruments, Inc. ATTN: Mr. K. E. Reynolds Main & Covert Streets Port Washington, New York
5	Zeiss - Aerotopograph ATTN: Mr. Marshall S. Wright 929 Highgate Road Alexandria, Virginia
2	Kern Instruments, Inc. ATTN: Mr. F. E. Davatz 120 Grand Street White Plains, New York
1	Director Physical Research Lab. Boston University Boston, Massachusetts

No. of Copies	Organization
1	Cornell University ATTN: Prof. Arthur J. McNair Center of Aerial Photographic Studies School of Civil Engineering Ithaca, New York
1	Franklin Institute ATTN: Mr. Charles Moench 20th St. & Benjamin Franklin Parkway Philadelphia, Pennsylvania
1	Massachusetts Institute of Technology ATTN: C. L. Miller Dept. of Civil & Sanitary Eng. Director Photogrammetry Lab. Cambridge 39, Massachusetts
3	New Mexico State College ATTN: Dr. George Gardiner State College, New Mexico
1	National Academy of Science ATTN: Dr. Pembroke J. Hart, Jr. Washington 25, D. C.
3	Ohio State University ATTN: Prof. Dr. Brandenberger Prof. A. R. Robbins Prof. Heiskanen Mapping & Charting Research Lab. Columbus, Ohio
1	Princeton University ATTN: Prof. Sumner B. Irish Department of Civil Engineering Princeton, New Jersey
3	Smithsonian Institute Astrophysical Observatory ATTN: Dr. F. L. Whipple Mr. Imre G. Isaacs Dr. Y. Kozai 60 Garden Street Cambridge 38, Massachusetts

DISTRIBUTION LIST

No. of Copies	Organization
2	Syracuse University L. C. Smith College of Engineering ATTN: Prof. Arthur Faulds Prof. Paul G. Brennan Department of Civil Engineering Syracuse 10, New York
1	Syracuse University ATTN: Photogrammetric Department Department of Civil Engineering Syracuse, New York
2	Smithsonian Institute ATTN: Dr. Karl G. Henize Dr. J. Allen Hynek Washington 25, D. C.
2	University of Illinois ATTN: Dr. H. M. Karara Prof. Milton O. Schmid Department of Civil Engineering Urbana, Illinois
1	University of Michigan ATTN: Prof. Edward Young Ann Arbor, Michigan
1	University of New York ATTN: Dr. W. M. Ewing Lamount Geological Laboratory New York, New York
1	University of Pennsylvania Computing Laboratory ATTN: Mr. John B. Crozier Philadelphia, Pennsylvania
1	Yale University Observatory ATTN: Dr. Dirk Brouwer New Haven 11, Connecticut
1	Mr. Robert Zurlinden 2118 - 37th Street, N. W. Washington 7, D. C.
1	Mr. Frederick J. Doyle Broadview Research Corporation 2139 Wisconsin Avenue, N. W. Washington 7, D. C.
1	V. Zay Smith, Associated Consulting Geologists ATTN: John McMurchy 1143 - 17th Avenue, S. W. Calgary, Alberta
10	The Scientific Information Officer Defence Research Staff British Embassy 3100 Massachusetts Avenue, N. W. Washington 8, D. C. Of Interest to: Professor E. H. Thompson University College London, W. C. 1 England
4	Defence Research Member Canadian Joint Staff 2450 Massachusetts Avenue, N. W. Washington 8, D. C. Of Interest to: National Research Council of Canada ATTN: Mr. T. J. Blachut Mr. G. H. Schut Ottawa 2, Ontario

AD ______________ Accession No. ______________ UNCLASSIFIED
Ballistic Research Laboratories, APG
CALIBRATION OF PC-1000 CAMERAS BY MEANS OF STAR PHOTOGRAPHY
Myron W. Lawrence

BRL Memorandum Report No. 1468 April 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

Calculations - Camera Calibration
Photogrammetry - Calibration
Cameras - Calibration

Calibration of three PC-1000 cameras was performed utilizing approximate zenith exposures of stars. The calibration consists of determining the focal length, principal point, and lens distortion of each camera and corresponding estimates of precision derived from a rigorous least squares solution. Field work and data reduction procedures are described. Graphical presentation of lens distortion and a discussion of the results are included.

AD ______________ Accession No. ______________ UNCLASSIFIED
Ballistic Research Laboratories, APG
CALIBRATION OF PC-1000 CAMERAS BY MEANS OF STAR PHOTOGRAPHY
Myron W. Lawrence

BRL Memorandum Report No. 1468 April 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

Calculations - Camera Calibration
Photogrammetry - Calibration
Cameras - Calibration

Calibration of three PC-1000 cameras was performed utilizing approximate zenith exposures of stars. The calibration consists of determining the focal length, principal point, and lens distortion of each camera and corresponding estimates of precision derived from a rigorous least squares solution. Field work and data reduction procedures are described. Graphical presentation of lens distortion and a discussion of the results are included.

AD ______________ Accession No. ______________ UNCLASSIFIED
Ballistic Research Laboratories, APG
CALIBRATION OF PC-1000 CAMERAS BY MEANS OF STAR PHOTOGRAPHY
Myron W. Lawrence

BRL Memorandum Report No. 1468 April 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

Calculations - Camera Calibration
Photogrammetry - Calibration
Cameras - Calibration

Calibration of three PC-1000 cameras was performed utilizing approximate zenith exposures of stars. The calibration consists of determining the focal length, principal point, and lens distortion of each camera and corresponding estimates of precision derived from a rigorous least squares solution. Field work and data reduction procedures are described. Graphical presentation of lens distortion and a discussion of the results are included.

AD ______________ Accession No. ______________ UNCLASSIFIED
Ballistic Research Laboratories, APG
CALIBRATION OF PC-1000 CAMERAS BY MEANS OF STAR PHOTOGRAPHY
Myron W. Lawrence

BRL Memorandum Report No. 1468 April 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

Calculations - Camera Calibration
Photogrammetry - Calibration
Cameras - Calibration

Calibration of three PC-1000 cameras was performed utilizing approximate zenith exposures of stars. The calibration consists of determining the focal length, principal point, and lens distortion of each camera and corresponding estimates of precision derived from a rigorous least squares solution. Field work and data reduction procedures are described. Graphical presentation of lens distortion and a discussion of the results are included.